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Art. XIV.—*The Geology and Petrology of the Warburton Area, Victoria.*

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(With Plate XVII.)

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(Note.—Numbers in brackets thus—No. (2462)—refer to slides in the University Collection.)

Introduction.

The area described in this paper is an approximately rectangular block of country, made up of the parishes of Yuonga and Warburton, the northern half of the parish of Woori Yallock, and the southern part of the parish of Gracedale (all in the County of Evelyn). It lies south of, and is contiguous with, the Black Spur Area.[8]

A geological sketch map has been prepared from parish plans, and compass and pacing traverses. Form lines have been drawn, based on aneroid traverses, in order to demonstrate the very rugged topography. Where geological boundaries are marked with broken lines, they are inferred from the mapping; full lines indicate boundaries which have been traced.

I am indebted to Dr. Summers, Dr. Stillwell, Mr. Singleton, Mr. Hauser, and the staff of the Geology School for their generous help, and to the University authorities, who made the work possible.

Previous Literature.

Scanty references to the district are found in the progress reports of the Geological Survey for 1876 and 1877, and in the annual report of the Secretary for Mines for 1907. In 1901 E. Hogg[12] in a paper on Victorian granitic types summarized the characters of the granodiorite from Old Warburton, and in the following year Professor J. W. Gregory[10] included the Warburton dacites in the Tertiary igneous rocks of Victoria. Short geological notes on the area are found in the *Victorian Naturalist* for 1904 (Chapman) and 1905 (Kitson). There is a brief report on the mining features of Hoddle's Creek by O. A. L. Whitelaw, in the *Records of the Geological Survey of Victoria* for 1906. Two important maps, prepared by J. C. Easton, appeared in the *Records of the Geological Survey* for 1908, accompanied by short reports. These show the boundaries of the igneous rocks and the Silurian for the Woori Yallock Basin, and the head of the Acheron and Yea rivers, with the Yarra. Professor E. W. Skeats[20, 21] in 1909 appreciated the Palaeozoic age of the igneous rocks. He observed the general similarity between the gneissic contact aureole at Warburton and that at Selby, and recognized the intrusive relation of the granodiorite to the dacite both at Warburton and at Nyora, despite the absence of gneissic rocks at the latter. J. T. Jutson[15] described the physiography and development of the Yarra in 1911; and in the *Records of the Geological Survey* for 1921, A. M. Howitt recorded the characters of the wolfram deposits at the head of Britannia Creek.

Physiography.

The Warburton area has a mountainous topography, which falls into four zones: (1) the east-west dacite range in the north, (2) the deep valley of the Yarra, (3) the mountains of granodiorite in the south-east corner of the area, and (4) the Silurian foot-hills in the south-west corner.

The east-west dacite range is bounded on its north side by the head waters of the Acheron, Watts, and Badger rivers, and on its south side by the valley of the Yarra. It slopes down from 4,080 feet at Donna Buang in the east, to 3,400 feet at Ben Cairn in the west. West of these it is deeply cut into by the north-south valley of the Don river, so that Mt. Toole-be-wong is all but isolated, being connected with the main range by a narrow neck at the head of the Don. Erosion has formed two low gaps in this neck—Don Gap (2,500 feet) and Panton's Gap (1,700 feet). The resistant granitic base of Mt. Toole-be-wong has diverted the erosion of the Yarra.

The valley of the Yarra is fully described by Jutson.[15] In the east it forms, in the Silurian sediments, a wide, mature valley. At Warburton, where a narrow tongue of dacites crosses the stream, it narrows into a deep rocky gorge, which opens again into a wide flat valley as the river progresses westwards.

The granodiorite mountains of the south-east corner are rugged, but less so than the dacitic ranges. They rise to about 2,000 feet. Mt. Little Joe (1,500 feet) in Warburton, consists of sediments, metamorphosed by the granodiorite, and thus rendered resistant to erosion.

To the south-west occur the low foothills of Silurian sediments, separated from the south-eastern zone by the Little Yarra river.

In the eastern part of the area the northern tributaries to the Yarra, from the dacite, are more numerous, more torrential, and generally stronger than those from the south. Owing to their torrential character they tend to form "alluvial fans" about their junctions with the Yarra, thus forming deposits of river gravels, which mask the igneous outcrops. In the western part of the area, the southern streams increase in importance, and the torrential character disappears.

According to the varying richness and depth of soil in these four zones, there is a marked difference in the vegetation, which increases in richness and intensity from the poorly clad Silurian with its poor, thin soil, through the granodiorite, to the richly forested dacite. The undergrowth shows a parallel enrichment.

The Silurian Sediments.

The oldest rocks outcropping in the area are moderately openly folded sandstones and mudstones of Silurian (Yeringian) age. Blue slates appear occasionally, and thin beds of conglomerate with sandstone pebbles have been observed along the Cement Creek road. The beds dip at up to 80°, and strike at 20° west of north, with anticlines from one to two miles apart. Local crumpling appears along some of the axes. The thickness of the bedding varies enormously.

This present survey has dealt very scantily with the sedimentary rocks. No new fossils were discovered. The following forms have been recorded at intervals by Mr. Chapman[3-5]:—

1. *From the junction of Woori Yallock Creek and the Yarra.*

   Conularia sowerbii; Fenestella margaretifera; Stropheodonta (Leptostrophia) alata; Trachyderma cf. squamosa; Turrilepas yeringae.

2. *From Starvation Creek.*

   Styliola fissurella; Panenka gippslandica; Paracardium filosum; Lunulicardium antistriatum.

These are all Yeringian in horizon.

The Igneous Rocks.

The igneous rocks of the area comprise an acid suite of lavas, hypabyssal intrusives, and plutonic and associated aplitic phases. The earlier, more acid varieties are generally covered by the later flows, and are only found in small peripheral patches, or where deep erosion has exposed them. Occasionally, small blocks of them have been brought up by the later intrusions. There is fairly complete evidence for the sequence of extrusion:—

1. Soda-rhyolite
2. α-quartz-biotite-dacite
3. β-quartz-biotite-dacite
4. Hypersthene-dacite
5. Felspar-hornblende-porphyrite
6. Granodiorite
7. Aplites, pegmatites, quartz-porphyries, quartz veins

—i.e., an acid to basic series of lavas, reverting to increasingly acid intrusive types.

The suite is genetically related to, and individually contiguous with the Black Spur suite.[8] The rocks are petrographically related to the Macedon, Dandenong Ranges, Marysville, and Taggerty complexes. Accordingly they are to be regarded as of the same age as these—Upper Devonian.

The Soda-Rhyolite.

Small outcrops of soda-rhyolite are found marginal to the southern boundary of the igneous rocks, generally in association with the α-quartz-biotite-dacite. The rhyolite appears in two phases, both finely porphyritic, which may both be present in one locality. The one phase is a dark, often tuffaceous, glassy rock, with numerous quartz phenocrysts of 1 mm. diameter: the other is a white rock with quartz and felspar phenocrysts both apparent, flow structure, and often greenish glassy patches. The white phase may represent the dark phase devitrified, though they might be separate intrusions.

Section No. (2,460) is typical of the white phase, from the road cutting west of Scotchman's Creek. This rock is a glassy porphyry. The phenocrysts consist of quartz, anorthoclase, orthoclase, and albite occasionally. Clots of secondary biotite flakes occur, representing a previous pyroxene or amphibole. Individual phenocrysts reach 2 mm. diameter, but the majority average 0.2 mm. They are much embayed. The anorthoclase crystals are commonly edged with a narrow microscopic rim of clear material, probably orthoclase or albite. Kaolinisation often renders the determination of the felspars difficult.

The groundmass is cryptocrystalline to glassy, consisting mostly of quartz. It shows beautiful flow bands which curve about the phenocrysts. Lenticles of coarser groundmass of finely microscopic texture are drawn out and curved concentric with the flow structure. Ilmenite and accessories other than apatite are absent.

A Rosiwal volumetric analysis shows the following proportions:—quartz 12.2, anorthoclase (and other felspars) 13.8, biotite 2.3, and groundmass 71.7.

A chemical analysis (No. 1) shows it to be equally as acid as the potash rhyolites of Narbethong (No. 3)[14] and Taggerty,[11] but poorer in total alkalies. The nearest approach to it of a soda-rich type is the quartz-keratophyre from Navigation Creek, Noyong, analysed by Howitt, and described by Skeats.[20]

Section No. (2,462) from the Cement Creek Road quarry is from the dark phase. Compared with the white phase, it appears rather richer in quartz phenocrysts, and the base is strongly glassy. Both anorthoclase and orthoclase are present, together with some oligoclase. There is considerably more biotite, as chloritised primary flakes, and an increase in ilmenite often altered to leucoxene. Flow structure is well marked.

Associated with this dark rock is the white phase, which is free from the tuffaceous fragments common to the dark rhyolite. These fragments are generally sedimentary in character.

In the cutting west of Scotchman's Creek the white rhyolite has been locally kaolinised by the intrusion of a dyke related to the felspar-hornblende-porphyrite, which outcrops nearby. The edge of the dyke is similarly altered.

Two small patches of the rhyolite are found on the road between Ben Cairn and Donna Buang, surrounded by felspar-hornblende-porphyrite, which when intruding the dacites, appears to have brought this large xenolith up with it. Fragments of the white rhyolite (?) are also found in the hypersthene dacite at the summit of Donna Buang.

The α-quartz-biotite-dacite appears to overlie the white rhyolite near the kaolin patch, and the dark rhyolite wherever the two are associated, while the rhyolite is always found resting on the Silurian sediments.

While the outcrops of the dark rhyolite appear to represent the same flow, its relationship to the white rhyolite is obscure. These rhyolite flows rarely exceed 30 feet in thickness.

The α-Quartz-Biotite-Dacite.

This rock is outcropping in small patches around the southern margin of the igneous rocks. Fresh specimens are a dark-blue grey colour, and strongly porphyritic. The phenocrysts are of quartz and white felspar, with numerous flakes of black biotite, set in a very fine-grained base. The phenocrysts vary somewhat in grain size. They may be as large as 5 mm. in diameter, but average 2 mm. The rock is quite distinct from the quartz-dacite of Maroondah Dam, but resembles somewhat closely the quartz-biotite-dacite of the Black Spur. Chemically it approaches closest to the composition of the quartz-dacite. It is to be regarded as an intermediate phase between these two. As in the soda-rhyolite, but to a lesser extent, the soda dominates over the potash.

A typical section No. (2.449) from the boundary of allotments 20, 21, Yuonga exhibits these intermediary characters. The rock is a porphyrite, with phenocrysts of quartz, felspar, and biotite set in a glassy to cryptocrystalline groundmass.

The quartz crystals are strongly embayed, and often cracked and shattered. They about equal the total felspars in volume. The largest phenocrysts are of quartz, and their edges are sometimes granulated. Plagioclase dominates the felspars as oligoclase (about $Ab_{75}An_{25}$), with some andesine and a little anorthoclase (?). The biotite belongs to two generations.

There are numerous flakes of strongly pleochroic brown biotite of primary habit. These invariably show a deposition of iron ore along the cleavages. In addition there are aggregates of structureless biotite with a deeper brown colour. These probably replace enstatite, which is found rarely as small remnants. Muscovite is fairly common, silghtly chloritic, and replacing biotite. Primary ilmenite is absent.

Section No. (2,450), a few feet from the base of this flow, shows a rather more basic plagioclase ($Ab_{65}An_{35}$), together with rare microperthitic orthoclase. The phenocrysts show fracturing and shearing, and are crowded together to the partial exclusion of the groundmass, which is full of biotite granules. Enstatites are rare, and occasional pyrite stringers are present. In No. 2,451, from the road cutting west of Scotchman's Creek, enstatite is again present, and also some microperthitic orthoclase (anorthoclase ?). The plagioclase is about $Ab_{70}An_{30}$. Muscovite is present, and primary ilmenite is characteristically absent.

The β-Quartz-Biotite-Dacite.

Only one small patch of this rock occurs within the area, near Sunny Lodge, north-west of Mt. Toole-be-wong, and marginal to the igneous lavas. Associated with it are tuffs which contain what are apparently fragments of rhyolite. This rock is the same as that described as quartz-biotite-dacite, from the Black Spur,[8] and does not call for further description.

Distinctions between the Quartz-Bearing Dacites.

The following Rosiwal analyses illustrate the distinctive differences of the quartz-bearing dacites:—

	I. Quartz Dacite	II. α-Q. B. Dacite	III. β-Q. B. Dacite
Quartz	9.56	20.82	11.46
Felspars	15.30	21.32	27.04
Biotite	3.82	10.22	15.58
Groundmass ..	72.32	47.64	45.65

Primary ilmenite is absent from I and II, but is commonly present in III. Deuteric chloritisation is characteristic of I and is absent from II and III. The original pyroxene in II was enstatite (?) while that of III was hypersthene. With respect to felspars, II appears to be intermediate between I and III.

It would appear that the extrusion from the magma chamber occurred at different times at different localities, giving rise to slightly differing local phases. The sequence of the α and β varieties cannot be determined in the field. They both pre-date the hypersthene-dacite; and it has been thought advisable from the suggestive indirect evidence to consider the α type as post-dating the quartz-dacite, but as preceding the β type.

The Hypersthene-Dacite.

The hypersthene-dacite outcrops over most of the northern part of the area, being contiguous with the hypersthene-dacite described from Mt. Juliet in the Black Spur area.[8] Just at Warburton a narrow tongue of it crosses the valley of the Yarra, and makes contact with the granodiorite. It is the thickest and most widespread of the effusives, but the estimation of the thickness is rendered difficult by the irregular contour of its junction with the Silurian, or other igneous types. At Ben Cairn and at Donna Buang it appears to be at least 2,000 feet thick.

In chemical and mineral composition it is so closely allied to the Mt. Juliet type, and the hypersthene-dacites of Macedon[22] and the Dandenong Ranges,[18, 21] as not to warrant a further description.

Felspar-Hornblende-Porphyrite.

This presents a facies previously unrecorded in the dacitic suites of Victoria. A section from the Don-road outcrop has been described by Junner[14] as an andesite; while a reference by Easton[7] to trachyphonolite just west of the Dee river may represent a border phase of the outcrop found there.

An analysis (No. 8) shows the rock to be closely similar to the granodiorite in chemical composition, and more acid than the hypersthene-dacite, so that it cannot be termed andesite. Moreover, its intrusive, dyke-like form precludes the name dacite. Hence it has been called "porphyrite." The prefix "felspar-hornblende" is added to distinguish it from the post-granodiorite hornblende-porphyrites of Selby and Dandenong,[21, 23] and to accord with the descriptive nomenclature adhered to throughout.

The outcrops are in the form of long narrow dykes, often with a strong dip. This dip, if taken in conjunction with the contours, accounts for the major irregularities of the various outcrops. It is significant that these dykes have been found only along the deeply eroded dacitic range from Donna Buang to Toole-be-wong (and in the Badger Valley ?) in the proximity of the granodiorite massif.

These great porphyrite dykes intruded the hypersthene dacite. At the immediate contact granulation has occurred in conjunction with chemical rearrangement. The hypersthene phenocrysts of the dacite have been altered, in some cases to a structureless biotitic mineral, and quite commonly to fibrous sheaves of, apparently, anthophyllite. Further outwards, up to 30 feet or more from the contact the granulation is the main alteration. The granodiorite is found intruded into the dykes in the Warburton contact zone. There is evidence also, from xenoliths, that they post-date the soda-rhyolite and the α-quartz-biotite-dacite, so that their position in the sequence of the types is fixed.

It seems probable that these porphyrite dykes represent tongues of magma from the uprising granodiorite fluid, and that they demonstrate the mechanics of the extrusion of the preceding lavas.

The various outcrops vary a great deal in the size of the phenocrysts, their proportion, and the nature of the groundmass. A very good exposure, obliquely transverse to one of the main dykes, is found along a fire-break on the southern slope of Ben Cairn. A series of specimens taken across the outcrop make it possible to correlate all the irregularities observed into progressive relationship and serves better to describe the character of the rock than specimens from any other locality.

It is possible to trace the rock through a glassy stage to a trachy-doleritic phase. This, in turn, is replaced by a finely porphyritic rock which transcends to a coarse porphyrite. From this stage, the size of the phenocrysts decreases, until a glassy border phase is again met with on the upper edge of the outcrop.

Specimens of the lower glassy phase show a dense black fine-grained rock, almost free from even minute phenocrysts, and exhibiting a fine, platy banding from differential movement. The banding is parallel to the wall of the dyke. In section No. (2,414), a few feet within the dyke, the rock has a trachy-doleritic texture, and consists of orthophyric prisms of felspar and green hornblende. The felspar is a labradorite plagioclase ($Ab_{30}An_{70}$). Occasional large phenocrysts of bytownite stand out. The hornblende prisms are generally altering to chlorite, and occasionally to epidote. Iron ore is noticeably subordinate. Section No. (2,415), from the same lower inner border phase, presents certain "orbicular" structures in a similar trachy-doleritic base. The outstanding feature is a quartz ovoid 1.5 cms. x 2.5 cms. This ovoid has smooth rounded walls, and is entirely crystalline. It consists mainly of quartz. A little andesine, and one crystal of microcline (?) appear near its outer edge. A few crystals of chloritised hornblende associated with epidote appear in the peripheral parts, and fine radial and hair-like microlites of hornblende abound in the quartz throughout. Epidote needles and granules are also found as minor constituents of the ovoid. They often appear at right angles to the wall, or parallel to it, suggesting a radial and concentric structure within the ovoid. Circular "orbicules" with an inner zone of hornblende and an outer rim of quartz (?) or, possibly, felspar are also observed. These are of microscopic dimensions. The hand specimens show distinct "orbicules" up to 0.5 cm. diameter. In section these show a nucleus of radially crystalline quartz surrounded by a zone of hornblende and, lastly, a fine rim of either quartz or felspar. These "orbicules" break out distinctly from the trachy-doleritic groundmass. All these orbicular phenomena seem related, and apparently owe their origin to the viscosity relations set up by sudden cooling (cf. Sederholm, p. 19).

Section No. (2,416) is cut from about 30 yards from the lower (southern) edge of the dyke outcrop. It is a porphyritic rock with phenocrysts of plagioclase and chloritised green hornblende, together with occasional biotites, and rare quartz crystals, set in a glassy groundmass. The plagioclases are bytownite (about ($Ab_{25}An_{75}$), with small quantities of andesine. It shows well-developed Ab twinning, and Carlsbad twins, and less frequently zoning. The crystals are generally corroded and often cracked and crushed. Clots of crystals are not uncommon. Individual phenocrysts are rarely larger than 2 mm. diameter, and average from 0.5 mm. to 1.0 mm.

The hornblende is possibly sodic. It is pleochroic from green to blue or yellow, and shows a high double refraction. It is often idiomorphic in section, and is generally altered to chlorite or a fibrous mineral. Less commonly it is altered to brown biotite of structureless character. Such biotite as occurs is often surrounded by a fringe of "intergrown" iron ore and quartz. "Mosaic" intergrowths of hornblende prisms and plagioclase are present.

The groundmass is highly glassy, and is full of fine grains of ilmenite, chloritised microlites of hornblende, and incipient microlites of quartz or felspar. Little stringers of quartz commonly penetrate the groundmass, and also the phenocrysts. Zircons are accessory.

Section No. (2,417) was taken from the centre of the dyke. The dominant phenocrysts in this are basic andesines ($Ab_{50}An_{50}$). These are much coarser in grain size than in the border phase, being commonly 4.5 mm., and larger in diameter. The smaller phenocrysts, also abundant, often show clotting together. Hornblende is rarely found, its place being taken by biotite, which now occurs in crystals showing normal structures. The groundmass is still strongly glassy, but is free from hornblende needles or granules, and contains more numerous and more strongly developed microlites of quartz and felspar.

This coarse central phase merges again into a finely porphyritic stage similar to that described above, and this passes into a fairly wide trachy-andesitic border phase. Section No. (2,418) from this upper (northern) border phase is very greenish owing to a richness in hornblende material. Clots of small hornblende crystals are set in a hyalopilitic base of plagioclase, hornblende, glass and iron ore. The groundmass makes up over 80 per eent. of the roek. Phenocrysts of felspar are small, and not common. They are of basic labradorite. Lens-shaped patches of quartz and felspar (orthoclase ?), and related veinlets, showing columnar growth from the walls inwards, are of common occurrenee. They represent the last part of the rock to consolidate. Some secondary biotite is developed from the hornblende.

All these types, in various associations, of which the finely porphyritic and the glassy to trachy-andesitic border phases are most general, are found recurring in the other dykes of felspar-hornblende-porphyrite.

It seems evident that it was intruded in an almost completely fluid state, and that erystallisation set in rapidly. In the outer phases the chilling gave mainly a glass: in the trachy-doleritie phase, viscosity was rapidly indueed giving orbicular developments and completer crystallisation, about many centres. Further in, the individual felspars and hornblende crystals developed freely for a time. The time of free development increased towards the centre, so that progressing inwards the felspars are larger and inereasingly acid. Differential movement is marked in the outer border phases. A further result of the slower central cooling has been to permit the intratelluric replacement of the hornblende by biotite to occur increasingly towards the centre of the dyke. The order of crystallisation of minerals was apparently—ilmenite, anorthite, hornblende, labradorite, andesine, biotite, quartz. The chloritisation may have been of " deuteric " origin. Larsen[16] quotes the reversion temperature of green hornblende to give a basaltie hornblende as 750° C. If this is so, then the dyke could scareely have been above 800° C. when intruded, and it must have cooled relatively slowly.

Granodiorite.

Two outcrops of granodiorite occur within the area. The one forms the northern end of a large massif extending from just south of Warburton township to as far south as Tynong, where it appears as a typical granite. The other outcrop is a stock-like body, of satellitic character, forming the core of Mt. Toole-be-wong and exposed on the western slopes, and the ridge of that mountain.

A summary of the characters of the granodiorite from Old Warburton has been given by Hogg[(12)] in a paper on Victorian Granites. An analysis (No. 9) gives further information.

In hand specimen it is an even-grained, holocrystalline rock, grey to white in colour, and consisting of quartz, felspar and abundant biotite, closely similar to the Braemar House granodiorite.[(22)] The Nyora rock is slightly coarser grained than the Warburton. The chemical analysis of the Braemar House granodiorite and the Warburton one, emphasize their close resemblance.

A typical section No. (409) from Scotchman's Creek is a fine-grained granodiorite rich in biotite. Plagioclase dominates over orthoclase. The plagioclase is an acid oligoclase (about $Ab_{80}An_{20}$) showing zonal structure, and twinning on both albite and pericline laws. It has well-marked edges except when it occurs as inclusions in the orthoclase, when the edges are generally corroded. The orthoclase occurs in large allotriomorphic plates, and tends to be microperthitic. The quartz also occurs in plates, and often contains numerous bubbles. It includes biotite. Zircons and apatites are present as accessories.

It differs then from the Braemar House granodiorite in possessing a more acid plagioclase. It is also richer in orthoclase as shown by the comparison of Rosiwal analyses:—

Braemar House.—Quartz 26.3, orthoclase 6.6, plagioclase 38.1, biotite 27.3, accessories 1.7.

Warburton.—Quartz 28.1, orthoclase 12.4, plagioclase 34.5, biotite 24.0; accessories 1.0.

The order of crystallisation was—(1) accessory minerals, (2) biotite, (3) plagioclase, (4) orthoclase, (5) quartz.

The granodiorite from Nyora is slightly coarser in texture and slightly richer in quartz, but is not different in any essential.

The granodiorite about the Backstairs Creek is very decomposed. Shafts have been sunk in this decomposed rock to a depth of 100 feet.

Quartz Nodules in the Granodiorite.

A distinctive feature of the Warburton granodiorite is the common presence in it of quartz nodules, varying in diameter from 1 cm. to 30 cms. or larger. The general size is from 3 cms. to 10 cms. The shapes of the nodules are irregular. They vary from subangular to subspheroidal, and are sharply differentiated from the granodiorite so that they weather out, with the appearance of partially waterworn boulders or pebbles.

The nodules consist of granular crystalline quartz, the individual grains being 2–3 mm. in diameter, generally transparent and colourless. In weathered specimens the quartz is often snow white, and when rubbed, after breaking open the nodule, the individual grains come loose like grains of rice. Some examples exhibit a tendency towards acicular growth, so that certain faces of the nodule truncate numerous grains, whilst other faces more or less at right angles, or at 60° to these former, tend to permit development of free crystals parallel to the faces. From this the subangular form arises. Generally these nodules consist entirely of quartz, but muscovite flakes have been found in some. Two nodules have been found enclosing tiny needles of black tourmaline, and another encloses what is apparently a small piece of granodiorite. Lastly, in one, a minute internal vugh was present. Such cases are all exceptional. These nodules are characteristic of the granodiorite close to the margin. This margin is also marked by the presence, in equally large numbers, of partly digested xenoliths, both of sedimentary and of igneous origin, and the individual nodules are commonly found close to the xenoliths. This association of nodules and xenoliths appears more significant when it is observed that the nodules are of rare occurrence in the Nyora margin granodiorite, which is typically free of xenoliths.

Such phenomena seem to be rather rare. Adams[(1)] describes quartz nodules in a granite from Ontario, where they are "confined to a portion 200 to 300 yards from the contact with an amphibolite, so that they cannot be regarded as a contact development." These nodules are spherical to ovoid, and predate the foliation of the granite. They are of a size similar to the Warburton nodules, and often show a small aggregation of black tourmaline near the centre. Microscopically they show an outer zone of quartz and sillimanite replacing an inner zone of quartz and muscovite. Radial structure is absent. Adams explains their origin (following von Chrustoff) as a primary magmatic differentiation, during the "crystallisation of a magma which was free to gather itself into rounded drop-like forms," i.e., partial immiscibility.

Per Geijer[9] describes quartz-muscovite nodules in a granite from Sydvarangar. No other minerals are present in the nodules. He considers that they have resulted from metamorphism of the granite.

Two other occurrences of quartz nodules are known in Scandinavia, but translations are not available.

It is difficult to explain the origin of the Warburton nodules. Lack of connected exposures renders any theory hypothetical. The nodules in the Warburton granodiorite are identical with those in the related aplitic dykes, and they may be related to the occasional quartz ovoids found in the felspar-hornblende-porphyrite, andesite xenoliths and in the hypersthene dacite. Possible origins seems to be (1) Immiscibility, cf. Adams; (2) Inclusion of quartzites, or reef quartz; (3) Pneumatolysis; (4) Viscosity, cf. Sederholm[19]; (5) Crystallisation as the result of supersaturation, cf. Bowen.[2]

Any theory of immiscibility is open to objection, both from the present accumulation of evidence opposing immiscibility in silicate melts of such composition, and from the irregular shape and structure of the nodules. The inclusion theory is practically precluded by the widespread occurrence of the nodules and the absence of quartzites, pure sandstones, or pre-granitic quartz reefs from the contact zone or its neighbourhood. Moreover the quartz has a magmatic character, and a coarseness of grain quite unlike that of xenoliths of sediments, but equal in size to that of individual crystals of the granodiorite, and the nodules occur equally bordering the dacite or the sediment.

There is very little evidence for a pneumatolytic origin, as shown by the disconnected occurrence of the nodules and the general absence of pneumatolytic minerals or of vughs in the nodules. They appear to have crystallised at about the same time as the granodiorite.

Sederholm[19] regards viscosity as a sufficient factor to produce such nodules as described by Adams if a local concentration in one mineral can be effected. Bowen[2] postulates that in assimilation, if a magma is saturated with respect to a mineral, then an attempt by the magma to absorb more of that mineral from a xenolith will cause supersaturation or, and, a nearby local deposition of that same mineral. The granodiorite must of necessity have been practically saturated with silica. Then any assimilation of dacite (SiO_2 60%) or sediment (SiO_2 60–70%) should have rendered it locally supersaturated, so that quartz would crystallise out locally. Moreover, the heat used up in assimilating the xenolith might produce locally viscous patches, so that the supersaturated quartz could not diffuse away into the main mass of magma.

The Hypabyssal Forms.

1. *Aplitic Dykes.*—Sections (467, 2,430, 2,431).

Two large aplitic tongues or dykes and one lesser one are found at Warburton passing from the granodiorite out into the dacite. All three appear to intrude the granitic and dacitic rocks equally.

The eastern tongue or dyke is a holocrystalline, porphyritic rock, with phenocrysts of quartz and perthitic orthoclase set in a coarse granular groundmass of quartz. The crystals are characterised by bubble-like inclusions. "Phenocrysts" and small crystals of pink andalusite are a feature of this dyke, and an occasional oligoclase crystal is seen. Biotite and muscovite are subordinate constituents, and brown tourmaline is often present.

The central tongue is easily the largest, and is characterised by the presence of quartz nodules, and ferromagnesian inclusions generally of biotite. It is rather coarser grained than the eastern aplite, and contains abundant muscovite. Quite a quantity of biotite, probably derived from digested inclusions, is present, and pyrrhotite is frequent. Andalusite is absent. Much of the orthoclase is sericitised, and some of the oligoclase also.

2. *Quartz Porphyry Dykes.*—Section (2,432 to 2,434).

Numerous quartz porphyry dykes are found in the Warburton granodiorite aureole. A series of eight, sub-parallel to the granodiorite boundary are found in the railway cutting west of the Scotchman's Creek. These dykes are from 4 to 20 feet wide, and cannot be shown on the general map of the area.

These dykes consist of small phenocrysts of quartz and microperthitic orthoclase set in a finely granular base of quartz and biotite granules. A little biotite is present, and mosaic patches of coarsely granular quartz are to be seen. These granular patches can be seen developing from the phenocrysts. The dykes commonly metamorphose the intruded dacites for about one to two feet from the contact.

3. *Pegmatites.*

These occur locally in both granodiorite and dacite, but it was not possible to trace their outcrops. They vary considerably from a finely granophyric rock to a coarse pegmatite with individual crystals up to 4 or 5 inches in diameter. A section No. (2,435) from one of the finer pegmatites shows a granophyric intergrowth of quartz and blue tourmaline.

4. *Quartz Veins.*

Quartz veins are found penetrating the schistose and gneissose dacites of the contact zone (Section No. 460) and also the granodiorite.. Section No. (2,436) of a vein in the granodiorite, $1\frac{1}{2}$ inches wide, is really an aplite.

All these dykes and veins post-date the granodiorite and represent the final stages of the igneous activity.

TABLE OF ANALYSES.

—	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2 ..	74·70	72·39	74·39	67·85	68·68	66·17	61·43	64·43	64·87	64·04
Al_2O_3 ..	14·73	4·42	14·28	14·65	14·61	14·75	15·95	16·52	16·24	13·58
Fe_2O_3 ..	1·00	0·56	0·52	0·64	0·81	0·30	1·21	1·70	1·03	0·80
FeO ..	1·13	0·30	1·09	3·40	4·33	4·73	5·64	3·80	4·80	4·47
MgO ..	0·32	1·85	0·27	1·39	1·14	1·71	2·83	2·37	2·62	2·64
CaO ..	0·92	0·85	0·24	3·05	3·01	3·31	4·98	3·80	3·20	3·52
Na_2O ..	4·13	5·93	2·78	2·12	3·15	2·45	2·96	2·50	2·83	2·42
K_2O ..	1·54	1·23	5·33	3·19	2·48	3·53	2·26	3·44	2·49	2·80
H_2O ..	0·66		0·22	2·25	0·32	0·66	0·81	0·43	0·50	2·25
		1·13								
H_2O ..	0·28		0·56	0·15	0·44	0·01	0·12	0·16	0·12	0·38
CO_2 ..	n.d.	n.d.	n.d.	..	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TiO_2 ..	0·19	n.d.	0·29	0·63	0·60	0·97	1·13	0·78	0·73	0·80
P_2O_5 ..	0·36	tr.	tr.	0·32	0·12	1·15	0·53	0·29	0·16	0·18
CoO ..	n.d.	..	..	..	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
NiO ..	n.d.	..	..	..	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Li_2O ..	n.d.	..	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	tr.
ZrO_2 ..	0·02	..	..	..	0·02	..	..	Nil	0·05	n.d.
Cl ..	0·03	..	n.d.	..	0·04	0·04	tr.	0·01	0·07	tr.
S ..	nil	..	..	nil	0·17	0·13	..	0·14	0·10	nil
SO_3 ..	nil	..	..	..	nil	nil	..	nil	nil	nil
BaO ..	0·01	..	..	..	0·01	n.d.	..	nil	tr.	n.d.
Cr_2O_3 ..	nil	..	..	..	nil	n.d.	..	nil	nil	n.d.
MnO_2 ..	0·05	0·01	n.d.	nil	0·03	0·20	nil	nil	nil	tr.
Less O_2 ..	..	..	..	..	0·08	0·06	..	0·07	0·05	..
Total ..	100·07	98·67	99·97	99·64	99·88	100·05	99·85	99·90	99·76	99·88
Sp. Gr. ..	..	..	2·49	2·68	..	2·71	2·78	..	..	2·72

TABLE OF NORMS.

—	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Quartz ..	40·98	..	36·20	33·36	30·54	28·14	18·66	23·42	25·44	25·20
Orthoclase	9·45	..	31·69	18·90	15·01	21·13	13·34	20·57	15·01	16·68
Albite ..	36·68	..	23·52	18·82	26·20	20·96	25·15	20·96	23·52	20·44
Anorthite	2·78	..	1·11	13·62	14·18	9·73	21·41	17·42	13·90	16·68
Corundum	5·61	..	3·47	2·75	1·33	3·16	0·80	2·24	3·47	2·14
Hypersthene	2·38	..	1·76	8·00	11·71	9·60	14·25	9·86	12·70	12·80
Magnetite	1·39	..	0·70	0·93	1·16	0·42	1·86	2·56	1·39	1·16
Ilmenite ..	0·32	..	0·61	1·21	1·11	1·82	2·83	1·52	1·52	1·52
Apatite ..	0·30	..	..	0·21	0·18	0·83	0·41	0·21	0·36	0·34
Pyrite ..	..	..	..	..	0·72	0·48	..	0·24	0·36	..
Class ..	I.	..	I.	I.	I.	II.	II.	II.	II.	II.
Order ..	3	..	3	3	4 (3)	4 (3)	4	4	4	4
Rang ..	1	..	1	3	3	2	3	3 (4)	3 (4)	3
Sub-rang	4	..	3	3	3	3	3	3	3	3

I. Soda-Rhyolite: Railway Cutting Corner, Warburton: (A.B.E.).

II. Quartz Ceratophyre: Nowa Nowa: (Howitt)[20].

III. Potash-Rhyolite: Archer's Lookout, Narbethong: (Junner)[14].

IV. Quartz-Dacite: Maroondah Dam, Healesville: (Evans)[8].

V. α-Quartz-Biotite-Dacite; Allot. 20-21 (Yuonga), Warburton; (A.B.E.).

VI. β-Quartz-Biotite-Dacite (Hypersthene bearing facies); Bladin's Quarry, Narbethong: (A.B.E.)[8].

VII. Hypersthene-Dacite; Mt. Juliet, Blake Spur Area; (Evans)[8].

VIII. Felspar-hornblende-porphyrite; Ben Cairn, Southern slope; (A.B.E.).

IX. Granodiorite; Scotchman's Creek, Warburton; (A.B.E.).

X. Granodiorite, Braemar House, Macedon; (Hall)[22].

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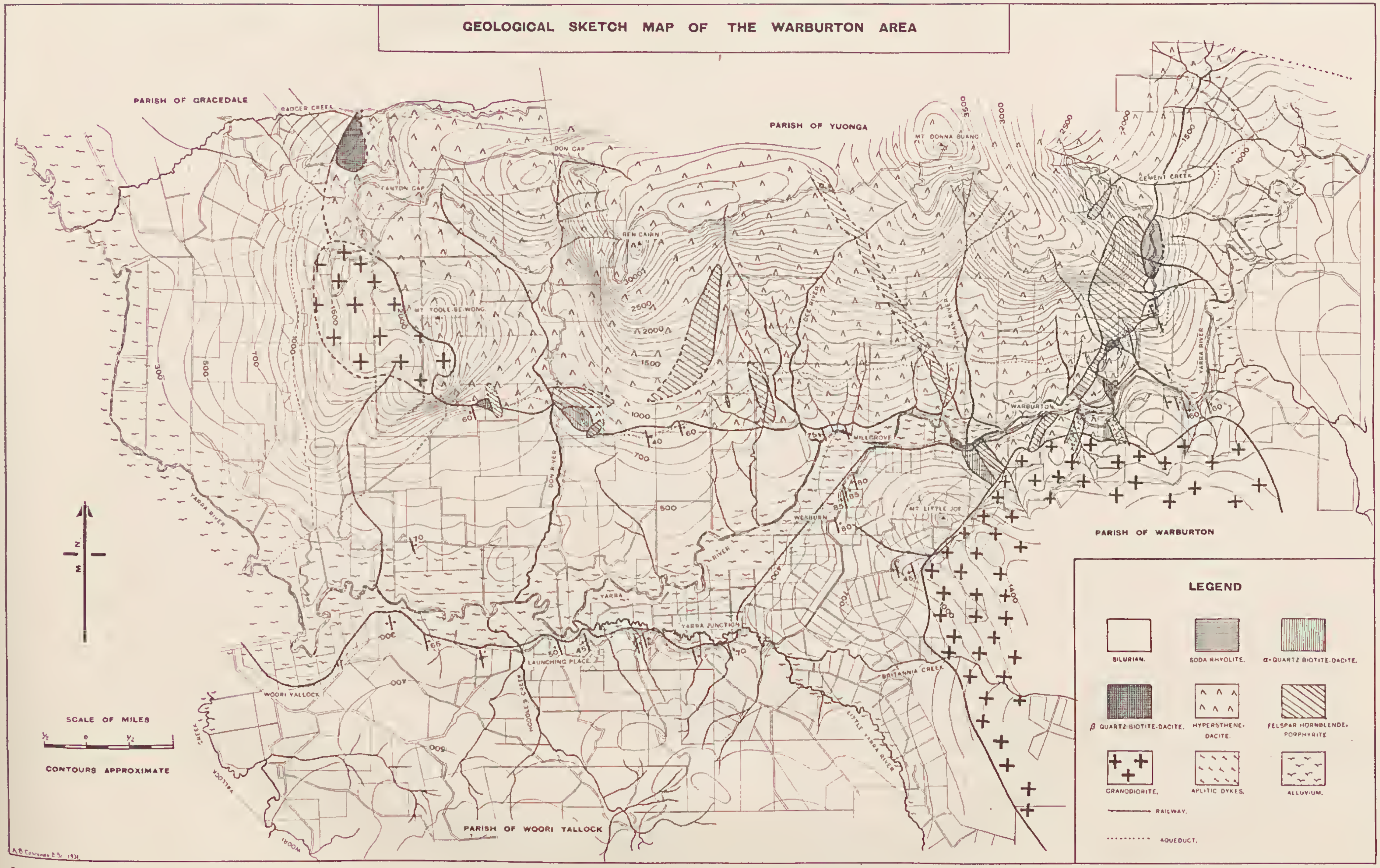
GEOLOGICAL SKETCH MAP OF THE WARBURTON AREA
PARISH OF GRACEDALE
PARISH OF YUONGA
PARISH OF WARBURTON
PARISH OF WOORI YALLOCK
BADGER CREEK
DON CAP
FANTON GAP
BEN CAIRN
MT. TOOLE-BE-WONG
MT. DONNA BUANG
CEMENT CREEK
WARBURTON
MILLGROVE
WESBURN
MT. LITTLE JOE
DON RIVER
YARRA RIVER
YARRA JUNCTION
LAUNCHING PLACE
WOORI YALLOCK
BRITANNIA CREEK
LITTLE YARRA RIVER
HODDLES CREEK
SCALE OF MILES
CONTOURS APPROXIMATE
LEGEND
SILURIAN.
SODA RHYOLITE.
α-QUARTZ BIOTITE-DACITE.
β QUARTZ BIOTITE-DACITE.
HYPERSTHENE-DACITE.
FELSPAR HORNBLENDE-PORPHYRITE.
GRANODIORITE.
APLITIC DYKES.
ALLUVIUM.
RAILWAY.
AQUEDUCT.

½" = 1 mile

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